Final Report

UNMANNED AIRCRAFT, DrN-35LS
LOSS OF AIRCRAFT AT SEA

19 FEBRUARY 2024

TIB/AAI/CAS.230

Transport Safety Investigation Bureau
Ministry of Transport
Singapore

27 November 2024

The Transport Safety Investigation Bureau of Singapore

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ABBREVIATIONS

BVLOS	Beyond Visual Line-of-Sight
FHT	Final Handling Test
GCS	Ground Control Station
GNSS	Global Navigation Satellite System
QRC	Quick Reference Card
UA	Unmanned Aircraft
UAP	Unmanned Aircraft Pilot
UAPL	Unmanned Aircraft Pilot Licence

SYNOPSIS

On 19 February 2024, an unmanned aircraft (UA) was operating a demonstration flight along a predetermined route over the sea to the Western Anchorage located south of Sentosa island, Singapore.

About seven minutes after the UA took off, its secondary Global Navigation Satellite System receiver sent erroneous latitude data to its flight computer. This triggered a 'POSITION X-CHECK FAIL' error message and resulted in the UA transitioning to the 'Land – GPS Lost' mode, in which mode the UA started to land at its current location.

The UA pilot, who was controlling the UA's beyond visual line-of-sight flight in autonomous mode via a Ground Control Station at a remote site, attempted to take over control of the UA but was unsuccessful as a wrong action was carried out. The UA continued descending to the sea and sank.

The Transport Safety Investigation Bureau of Singapore classified this occurrence as an incident.

UNMANNED AIRCRAFT DETAILS

Unmanned aircraft type	:	ST Engineering Aerospace DrN-35LS
Operator	:	Skyports Deliveries Pte Ltd
Aircraft serial number	:	AC32-140
Date and time of incident	:	19 February 2024
Location of occurrence	:	Western Anchorage, Singapore
Type of flight	:	Beyond visual line-of-sight

1 FACTUAL INFORMATION

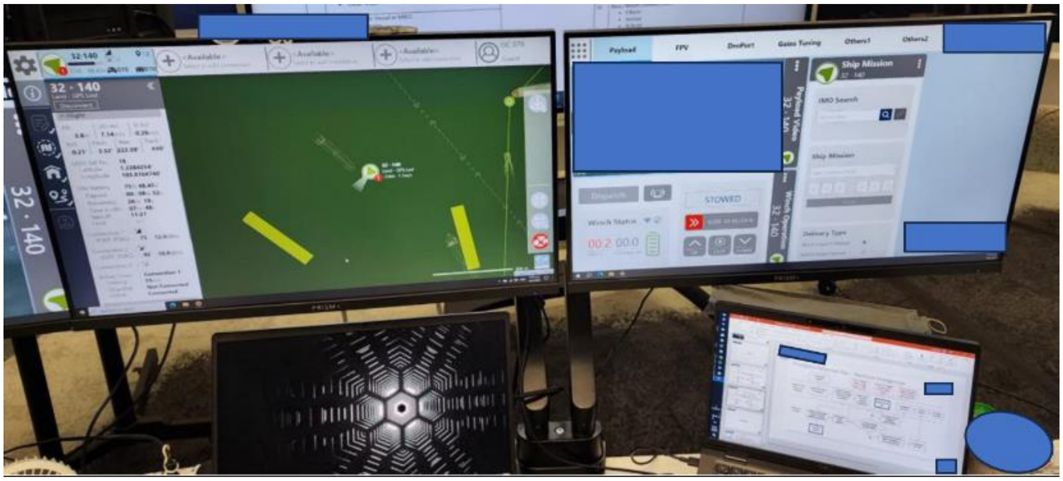
All times used in this report are Singapore Local Time (LT) unless otherwise stated. Singapore Local Time is eight hours ahead of Coordinated Universal Time (UTC).

1.1 History of the flight

1.1.1 On 19 February 2024, a model DrN-35LS unmanned aircraft (UA) (see **Figure 1**) was to operate a demonstration flight from Tanjong Beach, Sentosa island, Singapore to the Western Anchorage located south of the island. The UA was programmed to fly in beyond visual line-of-sight (BVLOS) mode to the planned waypoints autonomously. The UA took off at 11:37:58 hrs and flew along a predetermined route about 164 feet (50m) above the sea. The UA pilot (UAP) in charge of the demonstration flight manned the Ground Control Station (GCS) (see **Figure 2**) at a remote site. The UAP had the option of taking over control of the UA via the GCS (see paragraph 1.5.3 on the GCS set-up) when needed.

(Source: UA manufacturer)

Figure 1: DrN-35LS involved in the incident

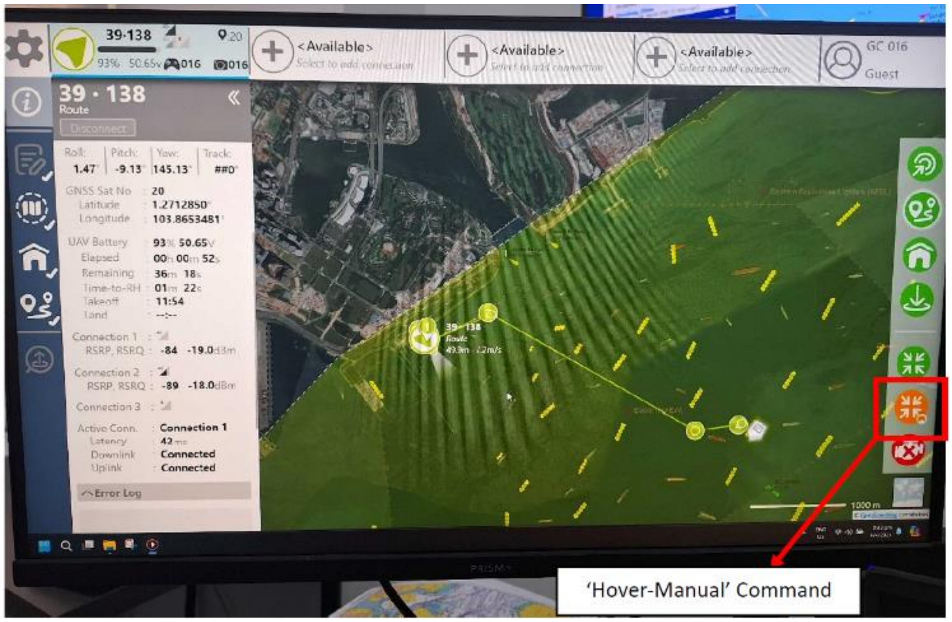


(Source: Operator)

Figure 2: Ground Control Station

1.1.2 At 11:45:50 hrs, a ‘POSITION X-CHECK FAIL’ error message appeared on one of the screens of the GCS (see paragraph 1.5.4 for more details), accompanied by an aural alert. At the same time, the UA reverted, as per design, to hover mode, i.e. stopping any horizontal movement, but maintaining its altitude.

1.1.3 The UAP had a window of five seconds to prevent the UA from transitioning to a controlled descent in the ‘Land – GPS Lost’ mode, as per design, by assuming manual control of the UA by clicking the ‘Hover-Manual’ command button on the GCS screen (see **Figure 3**) (see paragraph 1.5.5 for more details). However, the UAP attempted instead to take over control of the UA by pressing the ‘Hover’ command button on the UA controller (see **Figure 4**). The UA did not respond to the UAP’s input (see paragraph 1.5.3 for a description of the ‘Hover’ and ‘Hover-Manual’ modes).



(Source: Operator)

Figure 3: 'Hover – Manual' command button on the GCS screen

(Source: Operator)

Figure 4: UA controller

1.1.4 After five seconds of hovering and without receiving the 'Hover-Manual' command, the UA transitioned to the 'Land – GPS Lost' mode and started to descend for landing at its current location (about 2km from shore) (see paragraph 1.5.5). During the controlled descent, the UAP could still assume manual control of the UA by clicking the ‘Hover-Manual’ command on the GCS screen but the UAP did not do so.

1.1.5 About 60 seconds after the ‘POSITION X-CHECK FAIL’ error message was generated, the UAP realised that the correct action was to select the ‘Hover-Manual’ command button on the GCS screen to resolve the error but by this time the UA had already ditched and was sinking into the sea. **Figure 5** shows the trajectory of the incident flight.

1.2 Injuries to persons

1.2.1 There was no injury to any person.

(Source: Operator) (Annotation: TSIB)

Figure 5: Trajectory of the incident flight

1.3 Damage to UA

1.3.1 The UA sank and was not recovered.

1.4 UAP information

Age	44
Licence type	Unmanned Aircraft Pilot Licence (UAPL) (Class A & B Rotorcraft)
Issuing authority	Civil Aviation Authority of Singapore
Licence validity date	7 November 2026
Last Final Handling Test date	24 March 2023
Total flying hours	98hr 51min
Aircraft types flown	DrN-35, DrN-15, DLV-2, Swoop Kookaburra
Total hours on type	15hr 53min
Flying in last 90 days	5hr 42min
Flying in last 7 days	0hr
Flying in last 24 hours	0hr
Duty time in last 48 hours	16hr
Rest period in last 48 hours	32hr

1.5 UA information

1.5.1 The DrN-35LS is a six-rotor unmanned aircraft that can carry a payload of up to 3kg. The maximum take-off weight of the aircraft is 36.3kg. It is capable of performing BVLOS flights and flying up to an altitude of 1,000ft (about 305m) above mean sea level.

1.5.2 The status of the UA's flight parameters and GNSS position data are transmitted to the GCS and displayed on the screens of the GCS.

1.5.3 Ground Control System (GCS)

1.5.3.1 The GCS comprises a laptop, a UA controller and two screens. The laptop and screens allow a UAP to perform functions such as pre-flight check, mission planning and control the UA (e.g. take-off, landing and hovering).

1.5.3.2 The UA controller, which is connected to the GCS laptop, allows a UAP to control the UA via a control stick. The UA controller also provides some shortcut function buttons (e.g. hover, return home).

1.5.3.3 There are a limited number of function buttons on the UA controller. Only the commonly used control functions on the GCS screen for normal operations are made available on the UA controller. The control functions that are not commonly used, such as the 'Hover-Manual' function, can only be selected from the GCS screen but not from the UA controller.

1.5.4 Generation of 'POSITION X-CHECK FAIL' error message

1.5.4.1 The primary and secondary GNSS receivers send position data to the UA's flight computer. This latter cross-checks constantly the data. According to the UA manufacturer, a 'POSITION X-CHECK FAIL' error message will be generated when the position data from the two GNSS receivers differ by more than 20m for more than five seconds.

1.5.4.2 The UA is designed to hover, i.e. stopping any horizontal movement but maintaining its altitude for five seconds[1], when the 'POSITION X-CHECK FAIL' error arises. If the UAP does not assume manual control by clicking the 'Hover-Manual' command button on the GCS screen (see **Figure 3**) within this period, the UA will transition to the 'Land – GPS Lost' mode and land at its current location. During the landing phase, the UAP may still assume manual control of the UA by clicking the 'Hover-Manual' command button. The time available for the UAP to assume manual control once the UA transitions to the 'Land-GPS Lost' mode is dependent on the UA's altitude.

1.5.5 Manual control of UA

1.5.5.1 A UAP may take over control from an autonomous flight and hover the UA in the following two ways:

[1] Without valid GNSS data, the UA is unable to maintain its horizontal position. The longer the UA remains airborne, the more it will be susceptible to drift due to wind. The five-second hover was designed into the system with the expectation that a UAP will assume manual control immediately, while mitigating the chance that the UA will drift due to wind.

(a) By pressing the ‘Hover’ button on the UA controller – this method requires valid GNSS latitude and longitude data from both GNSS receivers in order to work.

(b) By clicking with a mouse the ‘Hover-Manual’ command button on the GCS screen – this method is used when GNSS latitude or longitude data is not valid.

1.6 Meteorological information

1.6.1 The incident happened during daylight hours and there was no precipitation. The air temperature was 33°C, visibility was 14km and wind was 050 degrees at 10kts. This weather condition was within the operating limits of the UA.

1.7 Flight recorders

1.7.1 The aircraft’s flight data was recorded at the GCS. This data was available to the investigation team for analysis.

1.8 Wreckage and impact information

1.8.1 The aircraft carried out a controlled descent towards the sea and sank. It was not recovered.

1.9 Medical and pathological information

1.9.1 The incident was reported to the TSIB about two days after it occurred. The UAP was not sent for medical and toxicological examinations.

1.10 Additional information

1.10.1 Review of flight data

1.10.1.1 The operator reviewed the recorded data of the incident flight and noticed that, at about 11:45:45 hrs (i.e. five seconds before the ‘POSITION X-CHECK FAIL’ error message was generated), the latitude data sent by the UA’s secondary

GNSS receiver to the UA's flight computer[2] changed momentarily from +1.2303818° (the correct latitude) to +130.0793918° (an incorrect latitude) and changed back to +1.2303639°. Global latitude data ranges from -90° (South Pole) to +90° (North Pole). The secondary GNSS receiver's latitude data of +130.0793918° was an invalid data. The UA manufacturer confirmed to the investigation team that the UA's flight computer software was not programmed to filter out invalid latitude or longitude data received from the primary and secondary GNSS receivers.

1.10.1.2 This differing latitude data from the primary and secondary GNSS receivers resulted in a GNSS positional difference of greater than 9,999.99m. This caused a loss of precision in the UA's flight computer computational results which the UA's flight computer was not designed to handle. As a result, the UA could behave erratically.

1.10.1.3 The UA manufacturer found that, although the unexpectedly large positional difference occurred only momentarily, the software calculated a positional difference of more than 20m that lasted for more than five seconds. This met the UA's design criteria for the generation of 'POSITION X-CHECK FAIL' error message.

1.10.1.4 The UA manufacturer also reviewed the recorded data of the five flights prior to the incident flight[3] but did not find any erroneous GNSS data.

1.10.1.5 The UA manufacturer forwarded the recorded GNSS data from the incident flight to the GNSS receiver manufacturer for review. The GNSS receiver manufacturer assessed that it was likely that the secondary GNSS receiver had been affected by external interference[4], resulting in erroneous GNSS data being sent to the UA's flight computer.

1.10.1.6 The investigation team is unable to establish whether and how external interference could have caused the erroneous GNSS latitude data in this incident.

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[2] The latitude and longitude data were sent from the GNSS receivers to the UA's flight computer at intervals of 0.2 seconds. In other words, the GNSS receivers generate latitude and longitude data at a rate of five times per second.
[3] The UA had flown a total of six flights, including the incident flight, since manufacture.
[4] According to the UA manufacturer, GNSS signals could be affected by external radio frequency transmissions in the same frequency bands of GPS signal (e.g. transmissions from radars, communication transmitters, GNSS jammers, and GNSS spoofers).

1.10.2 UAP training regime

1.10.2.1 The UAP had undergone the UA and GCS training conducted by the UA manufacturer, which had been assessed by the aviation regulator as meeting its regulatory requirements. The scope of the training included handling the 'POSITION X-CHECK FAIL' error. The training manual states that when this error arises, the UAP "may hold altitude by engaging the 'Hover-Manual' flight mode".

1.10.2.2 At the time of the incident, the Operation Procedures of the operator stated that it was the responsibility of the Operations and Training Manager[5] to ensure that UAPs complete all required training and hold the necessary skills and competencies.

1.10.2.3 It is also stated in the operator's Flight Operations Directive that:

(a) A UAP must complete a final handling test (FHT) (including all normal, non-normal and emergency procedures) annually, which would be assessed by a UAP instructor from the operator; and

(b) A UAP needs to operate a UA for two hours within any three consecutive calendar months as part of the recurrent flying training. However, the operator does not require such recurrent flying training to be conducted in the presence of a UAP instructor.

1.10.2.4 The UAP involved in this occurrence had last passed the FHT on 24 March 2023.

1.10.3 UAP's response to 'POSITION X-CHECK FAIL' error message

1.10.3.1 According to the UAP, the cause of the 'POSITION X-CHECK FAIL' error message was covered in training and the steps to handle the UA when this error occurred was known. The UAP indicated that this error had been encountered once prior to the incident during pre-flight check[6] while the UA was still on ground (and the flight mission was aborted as a result) but had not encountered this error while the UA was in-flight.

[5] Since the incident, the Operation Procedures has been updated and this responsibility falls on the Flight Operations Manager instead.
[6] The operator did not have record of this occurrence.

1.10.3.2 According to the UAP, when the 'POSITION X-CHECK FAIL' was encountered in this incident, the UAP was startled and did not respond appropriately. By the time the UAP recalled the appropriate action to take, the UA was already sinking.

1.10.4 Display of error messages on the GCS screen

1.10.4.1 When a UA encounters an error, the alerts and cues listed below will be displayed on one of the GCS screens. **Figure 6** is an illustration of the alerts displayed (not from the actual incident).

(a) An aural alert;

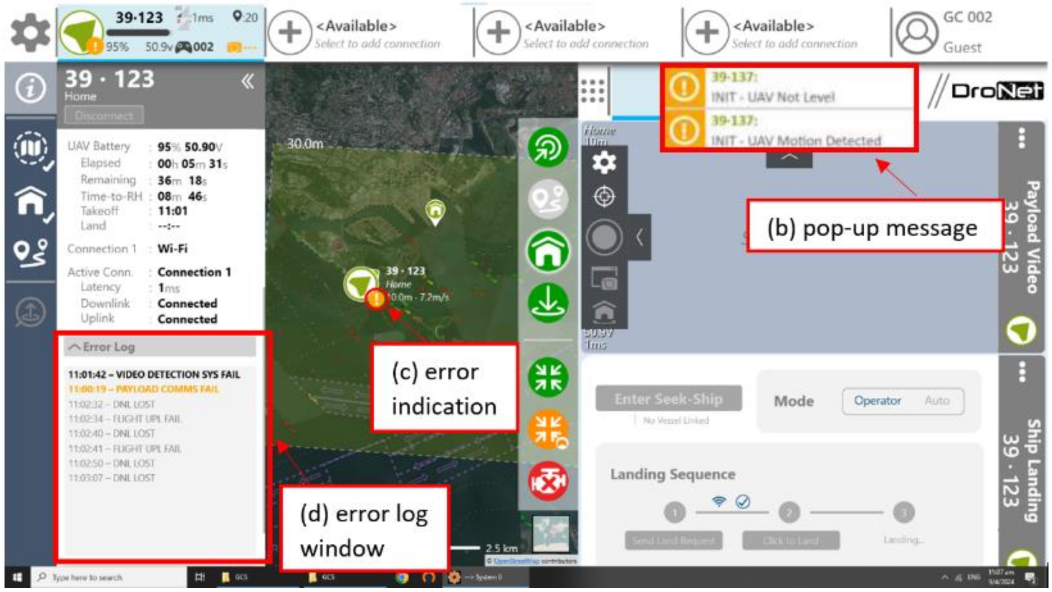
(b) A pop-up message on the top right of the menu bar will be displayed for five seconds;

(c) An error indication attached to the UA icon; and

(d) An error message in the error log window.

1.10.4.2 The 'Failure Management' section of the flight manual lists the considerations and the recommended actions to be taken by a UAP for each type of error that may be encountered. However, such considerations and recommended actions are not displayed on the GCS screen for a UAP's reference. According to the UA manufacturer, these considerations and recommended actions are not displayed because they can be lengthy and may clutter up the GCS screen.

1.10.4.3 Prior to the incident, the operator had, on its own initiative, compiled all the error types and the recommended actions for each type of error into an electronic document called the Quick Reference Card (QRC). During operations, the QRC must be opened on a separate laptop placed near the GCS for easy access. A UAP can use the laptop to display the section of the QRC on recommended UAP actions corresponding to a particular type of error.



(Source: Operator) (Annotation: TSIB)

Figure 6: Error messages displayed on the GCS screen

1.10.4.4 In this incident, the QRC was launched on a separate laptop and readily accessible by the UAP. However, the UAP said that, in the UAP's eagerness to recover the descending UA, the UAP did not refer to the QRC.

1.10.5 Regulatory requirements for UA operations

1.10.5.1 This incident occurred when the UA was in BVLOS operations, for which the aviation regulator has the following requirements:

(a) The UA shall remain within the specified area of operation at all times, and

(b) The flight time of the UA over persons is minimised.

1.10.5.2 The aviation regulator had reviewed the operator's BVLOS operations and was satisfied that the operator had complied with the requirements for BVLOS operations.

1.10.5.3 The aviation regulator had also reviewed the operator's Operation Procedures and assessed that the procedures were acceptable.

1.10.5.4 As mentioned in paragraph 1.4, the UAP held a Class B UAPL. According to the legislation[7], a holder of Class B UAPL must complete a refresher training at least once a year. This refresher training must be conducted either by a UA training organisation or by a UAP instructor of the employer.

[7] Paragraph 37(4) of the Air Navigation (101 – Unmanned Aircraft Operations) Regulations states that a holder of a UA pilot licence with a rating in Class B must complete appropriate refresher training in respect of each rating in Class B, at least once a year, conducted by an Unmanned Aircraft Training Organisation or a UA operator permit holder by whom the holder of the UA pilot licence is employed or engaged, failing which the UA pilot licence expires in respect of the rating at the end of one year after the later of —

(a) the date on which that rating was specified on the UA pilot licence; or

(b) the date on which the UA pilot last completed Class B refresher training in respect of that rating.

2 ANALYSIS

The investigation looked into the following:

(a) Probable cause of erroneous GNSS data

(b) Generation of 'POSITION X-CHECK FAIL' error message

(c) Recurrent training regime

(d) Displaying of recommended actions on the GCS screens when an error is encountered

2.1 Probable cause of erroneous GNSS data

2.1.1 According to the GNSS receiver manufacturer, it was likely that the secondary GNSS receiver had been affected by external interference. The investigation team was unable to establish whether and how external interference could have caused the erroneous GNSS latitude data.

2.2 Generation of 'POSITION X-CHECK FAIL' error message

2.2.1 The UA's flight computer software was not programmed to filter out the invalid latitude data of +130.0793918° received from the secondary GNSS receivers. In trying to process this invalid latitude data, the software generated an unexpected 'POSITION X-CHECK FAIL' error message.

2.2.2 Even though the erroneous latitude data from the secondary GNSS receiver had occurred only momentarily, the large magnitude of the difference between the positional data from the primary and secondary GNSS receivers caused a loss of precision in the UA's flight computer computational outcomes, resulting in the unexpected generation of a 'POSITION X-CHECK FAIL' error message.

2.3 Recurrent training regime

2.3.1 As mentioned in paragraph 1.10.2.3(b), the operator required its UAPs to operate a UA for at least two hours within any three consecutive calendar months as part of their recurrent flying training. The operator did not require such recurrent flying training to be conducted in the presence of a UAP instructor of the operator. The investigation team opines that such an arrangement would not allow for a UAP's level of competency to be objectively assessed. For example, a UAP may consider that he has performed a particular emergency procedure satisfactorily when in fact he might not be aware of his own shortcoming. It would seem desirable for such recurrent training to be conducted in the presence of a UAP instructor.

2.3.2 There was no record that the 'POSITION X-CHECK FAIL' error message had occurred in flight besides this incident. This meant that UAPs may practise and be objectively assessed on the competency to handle this error only once a year during FHTs. While the mishandling of the UA in this incident cannot be directly attributed to inadequate training, UAPs could be more conversant in handling UA errors, especially those that occur infrequently, if there were more opportunities for UAPs to be objectively assessed in all normal and non-normal procedures, including emergency procedures.

2.4 Displaying of recommended actions on the GCS screen when an error is encountered

2.4.1 When an error is encountered, the corresponding aural and visual alerts to the UAP will be displayed on the GCS screens. While the fight manual lists the recommended actions for each type of error, these actions are not displayed on any of the GCS screens. According to the UA manufacturer, this was because the recommended actions can be lengthy and may clutter up the GCS screens.

2.4.2 To its credit, the operator had developed a Quick Reference Card (QRC) that presents to the UAP the recommended actions. While the QRC is a useful reference for UAPs, it is only available on a separate laptop and using the QRC requires a UAP to momentarily shift his attention away from the GCS screens and perform the necessary searching and clicking on the laptop before the recommended actions are displayed. To reduce the time needed for UAPs to react to an error, it would be desirable that the corresponding recommended actions be shown immediately on the GCS screen in conjunction with the display of the error message or alert.

2.4.3 As regards the 'POSITION X-CHECK FAIL' error message, a UAP will have only five seconds to react correctly before the UA starts to descend for landing. If a UAP has not committed to memory that he needs to assume manual control by clicking the 'Hover-Manual' command button on the GCS screen, it is doubtful the UAP will have time to consult the QRC on the separate laptop. Thus, when an error message arises and where there is not enough time for UAPs to consult the QRC, it would be ideal for UAPs to commit such time critical actions to memory instead of having to refer to the QRC or prompt messages on the GCS screens.

3 CONCLUSIONS

From the information gathered, the following findings are made. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

3.1 According to the GNSS receiver manufacturer, it was likely that the secondary GNSS receiver had been affected by external interference which caused erroneous GNSS latitude data to be sent to the UA's flight computer. The investigation team is unable to establish whether and how external interference could have caused the erroneous GNSS data.

3.2 The UA's flight computer software had not been programmed to check whether latitude data received from the secondary GNSS receiver was valid or not.

3.3 According to the UA manufacturer, although the erroneous latitude data from the secondary GNSS receiver occurred only momentarily, it resulted in a positional difference that was larger than what the UA's flight computer software was designed to handle. As a result, the software unexpectedly generated the 'POSITION X-CHECK FAIL' error message.

3.4 According to the UAP, when the 'POSITION X-CHECK FAIL' error message occurred in-flight during the incident, the UAP was startled and did not immediately assume manual control of the UA by clicking the 'Hover-Manual' command button on the GCS screen. By the time the UAP recalled the appropriate action to take, the UA was already sinking.

3.5 There were not many opportunities for UAPs to be objectively assessed on their competency in all normal and non-normal procedures, including emergency procedures.

3.6 The GCS screens did not display the recommended actions when error messages occur. The operator had compiled a quick reference document for use by UAPs, which was accessible on a separate laptop. However, it is doubtful a UAP will have time to locate the relevant recommended actions from the quick reference document on the laptop when the 'POSITION X-CHECK FAIL' error message arises as there is only five seconds to react before a UA starts to descend.

4 **SAFETY ACTIONS**

Arising from discussions with the investigation team, the organisations have taken the following safety action.

4.1 The UA manufacturer has updated the UA's flight computer software to:

(a) check for invalid GNSS latitude and longitude data; and

(b) enable the UA's flight computer to handle a large magnitude of difference of positional data from the primary and secondary GNSS receivers.

4.2 The operator has conducted refresher training for all its UAPs in handling all emergency procedures, in particular handling the 'POSITION X-CHECK FAIL' error message.

5 SAFETY RECOMMENDATIONS

A safety recommendation is for the purpose of preventive action and shall in no case create a presumption of blame or liability.

5.1 It is recommended that the operator:

(a) Consider increasing the frequency of refresher training sessions that are to be conducted by an instructor UAP. [TSIB Recommendation RA-2024-005]

(b) Review the extent to which UAPs are required to commit to memory UAP actions that are time critical. [TSIB Recommendation RA-2024-006]

5.2 It is recommended that the UA manufacturer consider developing a method to make readily available the recommended actions when an error is encountered. [TSIB Recommendation RA-2024-007]